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CALCULATION OF HEAT TRANSFER TO THE GUN BARREL WALL

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I. INTRODUCTION

There has been an evolution of the idea that erosion of metal from the surface of gun tubes is controlled by the heat transfer during the ballistic cycle. Despite the arguments that chemical surface reactions or mechanical friction may be major contributors, the intuitive appeal of heat transfer control persists.

Early efforts at correlating erosion rate with heat transfer were limited to inferences about the heat transfer rate from measured ballistic variables. Nordheim's methodology[1] was used by Jones and Breitbart[2] to compute heat transfer and thus wear. UK investigators used the Hicks-Thornhill methodology[3] to correlate wear with the maximum computed temperature rise. Smith and O'Brasky[4] used Nordheim's method to obtain a surface temperature and with it devised an empirical correlation for erosion rate.

All these methods depend on a wall surface temperature obtained from simplifying assumptions about the flow inside the gun. No coupling of the flow to the heat transfer appeared until Shelton, et al[5], calculated heat transfer to the tube wall while simultaneously calculating the time and space dependent flow in the barrel. Shelton's analysis simplified the flow by assuming it was a one phase gas flow.

Attempts at calculating the two phase flow have just recently produced some reasonable agreement between calculated and measured ballistics. Gough's analysis[6] has been seen to correctly predict

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[1] *L.W. Nordheim, H. Soodak and G. Nordheim: "Thermal Effect of Propellant Gases in Erosion Vents and Guns," National Defense Research Committee Report A-262, March 1944.*

[2] *R.N. Jones and S. Breitbart: "A Thermal Theory for Erosion of Guns by Powder Gases," BRL Report 747, January 1951.* (AD #801741)

[3] *J. Corner, Theory of the Interior Ballistics of Guns, Wiley and Sons, Inc., New York, 1950.*

[4] *C.S. Smith and J.S. O'Brasky: "A Procedure for Gun Barrel Erosion Life Estimation," Proceedings of the Tri-Service Symposium on Gun Tube Wear and Erosion, March 1977.*

[5] *S. Shelton, A. Bergles and P. Saha: "Study of Heat Transfer and Erosion in Gun Barrels," US Air Force Armament Laboratory Report AFATL-TR-73-69, March 1973.*

[6] *P.S. Gough: "Numerical Analysis of a Two Phase Flow with Explicit Internal Boundaries," IHCR 77-5, US Naval Ordnance Station, April 1977.*

pressure waves in large caliber guns[7]. An inference may be drawn that if the measurable behavior is correctly predicted, the unmeasurable may be reasonably accurate. In that vein, there should be a prospect of calculating the heat transfer once the core flow calculation has been established. Present research is attempting to do both simultaneously with two dimensional, two phase analyses.

This paper will report a calculation of the heat transfer to the wall of a 155mm howitzer from the zone 8S XM203E2 charge minus its wear-reducing additive, using the Gough analysis for the core flow with a simple pipe flow correlation for the heat transfer coefficient to the wall surface. The results will be compared to experimental measurements made by Ward and Brosseau[8].

II. RESULTS

The pipe flow correlation for heat transfer coefficient is after Holman[9]:

$$q = h(Tg-Ts), \tag{1}$$

where
- q = heat transfer rate,
- h = convective heat transfer coefficient,
- Tg = core gas temperature, and
- Ts = wall surface temperature.

approximated by

The convective heat transfer coefficient, h, is defined as

$$h = \frac{\lambda}{D_h}\left[3.65 + 0.243(R_e^{0.8})(P_r^{0.4})\right], \tag{2}$$

---

[7] *A. Horst, C. Nelson and I. May: "Flame Spreading in Granular Propellant Beds: A Diagnostic Comparison of Theory to Experiment," AIAA Paper 77-856, July 1977.*

[8] *J.R. Ward and T.L. Brosseau: "Effect of Wear Reducing Additives on Heat Transfer into the 155mm M185 Cannon," BRL Memorandum Report 2730, February 1977.* (AD #A037374)

[9] *J.P. Holman: "Heat Transfer," McGraw-Hill, 1968.*

where λ = thermal conductivity of propellant gas,

D_h = hydraulic diameter,

R_e = Reynolds number, and

Pr = Prantl number.

The hydraulic diameter is related to the tube radius by

$$D_h = 2\epsilon R_T \left[1 + 2 R_T \frac{\epsilon}{D_p} \right] , \qquad (3)$$

where ε = porosity,

R_T = tube radius, and

D_p = particle diameter.

The analysis for the core flow (assumed to be unaffected by the boundary layer) is that of Gough[6]. The calculation starts with a cold bed of propellant at rest in the chamber. Igniter gas input simulates the convective processes which lead to ignition, bed motion, flame-spreading, and projectile motion. The two phase flow accounts inter alia for bed compaction, bed stagnation at the projectile base, and wave motion in the chamber, all of which would have profound influences on the gas flow and therefore the instantaneous heat transfer.

The solution in the tube wall, to obtain the surface temperature, assumes a cubic profile integral approximation. This method has been shown to produce a surface temperature change error of about 2% for a constant heat flux and 6% for a linearly increasing flux[10].

Figure 1 presents the calculated heat transfer rate and wall surface temperature versus time from gun igniter flow initiation. The axial distance is 6mm (0.25 inch) forward of the commencement of rifling.

The calculated cumulative heat transfer at 60ms was 1.5 J/mm^2.

[10] *C.W. Nelson: "On Calculating Ignition of a Propellant Bed," BRL Report ARBRL-MR-02864, September 1978.* (AD #A062266)

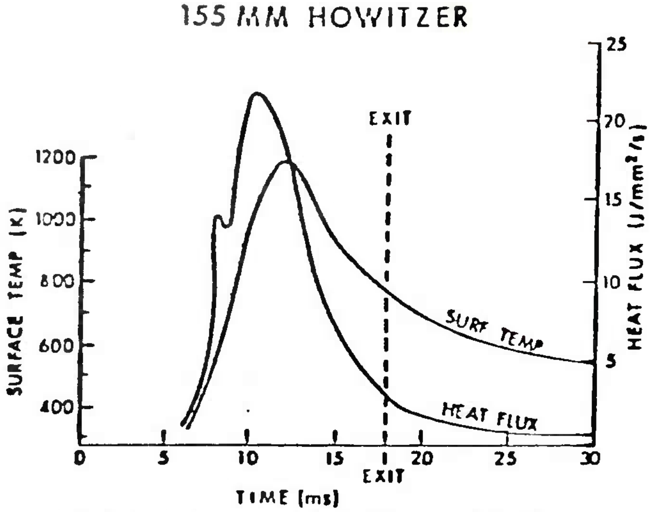

Fig. 1. Calculated Heat Flux and Wall Temperature

III. DISCUSSION

Measurement of the heat transfer in the 155mm howitzer was made by Ward and Brosseau[8]. With four thermocouples, the temperature distribution was estimated inside the tube wall at 100ms after ignition. Graphical integration of the distribution was used to estimate the heat transfer on the assumption that no transfer occurred from the wall after projectile exit at about 20ms. For the charge simulated in the calculation, the measured heat absorbed by the tube wall was 1.3 J/mm^2.

This calculation was intended only as a test to estimate the overall error inherent in NOVA's approach to the wall heat transfer problem. NOVA addressed the core flow; the heat transfer to the wall was an inexpensive aside. The pipe flow correlation should not be expected to be accurate in the gun condition which departs so much from a developed one phase steady flow.

Measured heat flow for this gun was 1.3 J/mm^2 whereas the calculated value is 1.5 J/mm^2. Simple remedies of adjusting constants may correct the present answer but cannot be expected to provide a general correction applicable to other gun calculations. For the present, it would be speculation to allot error contributions to the several simplifications assumed in the formulation.

To avoid a rewrite of part of the code, it was assumed that tube emptying after projectile exit would be adequately simulated by making the tube indefinitely long. Such flow would be different from flow emptying to one atmosphere pressure, but whether this would be critically different has not been established. Of the total 1.5 J/mm^2 delivered to the barrel wall, 1.2 J/mm^2 was transferred before projectile exit.

It is interesting to note that the predicted peak wall temperature (1,200K) was well below the melting point of the steel (1,770K). If the erosion is high because of melting, the calculation that predicts a total heat well above the measured heat should come closer to the melt temperature than one that calculates the correct lower total heat. A too low peak temperature would result from a too slow heating or too high conductivity of the tube wall. Given the state of knowledge of the conductivity, the culprit seems more likely to be the heat transfer rate during the early heating phase.

In similar calculations with the zone 8 XM201E2 charge, Vassallo[11] found the peak surface temperature was well below the melting point of steel. He predicted a surface temperature of 1,300K and concluded the erosion resulted from surface reaction effects.

The modest error resulting from this first time calculation promises that some reasonable improvements may narrow the gap. It is limited, however, to situations where no melting occurs and where any chemical reaction heat release can be combined with purely convective phenomena. In its present form, it could be used as a method for first estimates of wear. Since it overpredicts the heat transfer and since erosion has been found to vary with heat transfer, it would lead to conservative estimates of the erosion.

IV. CONCLUSIONS

1. The NOVA Code overestimates heat transfer to the gun barrel wall in the origin of rifling region for the zone 8S, XM203E2 charge without additive.

2. The peak surface temperature computed by the NOVA Code for the zone 8S charge minus wear-reducing additive is 1,200K which is well below the steel melting temperature.

[11] *F.A. Vassallo and W.R. Brown: "Shock Tube Gun Melting Erosion Study," BRL Contract Report ARBRL-CR-406, August 1979.* (AD #A076219)

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